4.—Tertiary Sediments at Coolgardie, Western Australia

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Palynological studies have been carried out on carbonaceous sediments from Rollo's Bore and Shaft and Olsen's Claim, all located about 1½ miles east of Coolgardie Railway Station. The results of these examinations indicate the presence of about 400 feet of Upper Eocene or Lower Oligocene strata, lying in a small depression in the Precambrian Shield. The section in Rollo's Bore includes brown coal, carbonaceous clays and immature boghead coal. These sediments are considered to be of lacustrine origin and to have been deposited, possibly in a coastal lake, during a physiographical cycle initiated by the epeirogenic movements accompanying the Upper Eocene marine transgression.

Pollen grains of *Nothofagus* are abundant in the sediments and are associated with pollens of proteaceous and podocarpaceous affinities. These microfloral assemblages represent the farthest inland and most northerly occurrence of the Lower Tertiary "*Nothofagus*-flora" yet recorded from Western Australia.

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Introduction

Precambrian igneous and metamorphic rocks in the Coolgardie area are usually obscured by deposits of alluvial, eluvial or chemical origin. Blatchford (1899) described these superficial deposits in some detail, and recently McMath (in McMath, Gray and Ward, 1953) proposed a classification of them. He recognized residual or eluvial soils, alluvial and aeolian deposits, laterites, and "cements" formed *in situ* by the decomposition of basement rocks. In most places in the Coolgardie district these deposits are undoubtedly a product of the present physiographic cycle and seldom exceed five or six feet in thickness.

Sediments of an entirely different type, however, are known in a small area lying to the east and south-east of Coolgardie Railway Station (Fig. 1). Here a roughly circular depression in the Precambrian crystalline com-

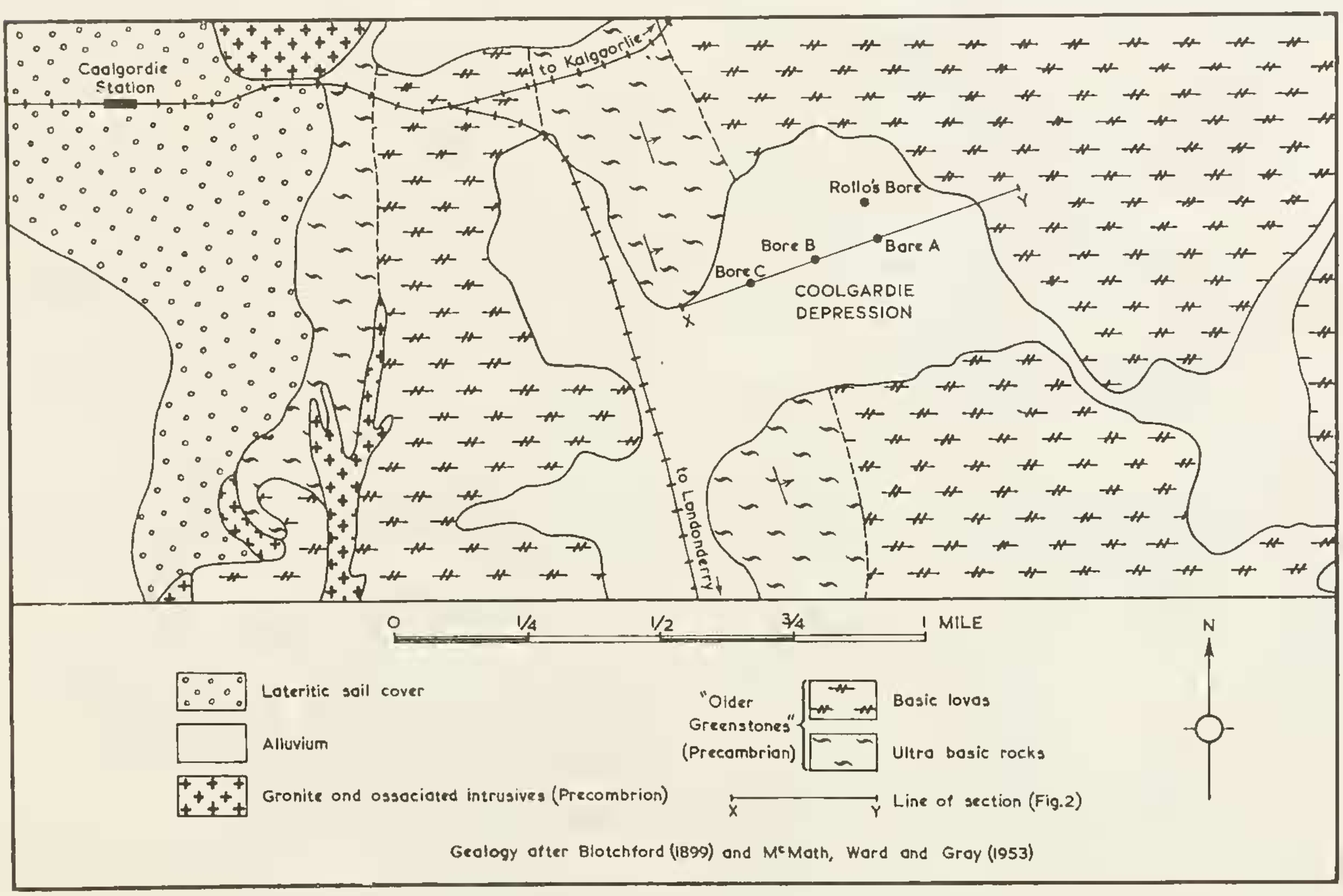


Fig. 1

plex, little more than half a mile across, is occupied by a sedimentary sequence having a maximum known thickness of 400 feet. The existence of this minor basin has been recognized since the earliest days of gold mining at Coolgardie, and between 1892 and 1897 a number of bores were sunk in the area. Rollo's Bore, situated about 1½ miles east of Coolgardie Railway Station was the deepest of these, and passed through 400 feet of more or less carbonaceous strata before entering ultra-basic metasediments. Exploitation of "deep leads" at Kanowna and Siberia encouraged further drilling in the neighbourhood of Rollo's Bore, and between 1897 and 1900, an additional series of boreholes was sunk to test the depth and distribution of the sediments. Logs of these bores were published by Campbell (in Maitland, 1901), together with a generalized map and section of the basin. Reconstructions of the sections in these bores are shown in Fig. 2, and Fig. 3 is a modification of Campbell's section.

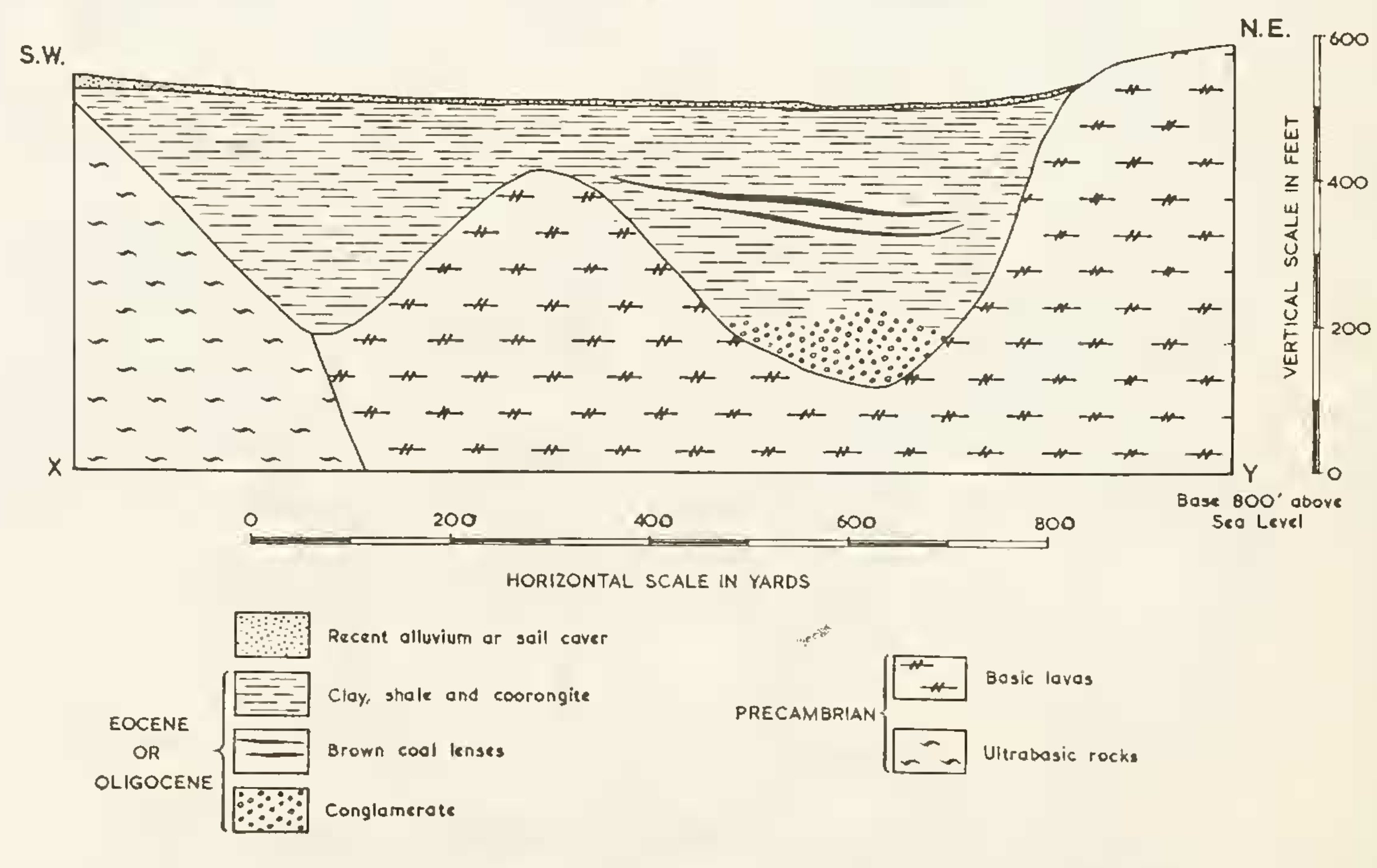
Available information from borehole logs suggests a fairly steep-sided depression, the deepest parts of which lie along its northern and western margins. The slope of the basement on the south-western side appears to be more gradual than on the northern and western margins, and the log of Bore B implies the presence of a central elevation rising about 200 feet above the floor of the depression.

Blatchford (1899, p. 22) gave a detailed section of the strata encountered in Rollo's Bore, and this is reproduced in Fig. 2.

The occurrence of brown coal in the borehole aroused interest at the time and led to some further unsuccessful prospecting in the vicinity. The shaft on Olsen's Claim, for example, was apparently sunk in an attempt to exploit the brown coal deposits. Its precise position is uncertain, but said by Simpson (1899, p. 58) to be "near Rollo's Bore". Speculation as to the age of the carbonaceous sediments also occurred in the early part of the present century. Blatchford recorded fossil leaves, some of which he assigned to the Eucalypti, from a depth of 380 feet in Rollo's Bore, and considered these to be of late Tertiary or Recent age. *Dryandra* was identified by Simpson (1902, p. 54) from the shaft on Olsen's Claim, and taken by him to indicate a Pleistocene age for the deposits. Two years later, however, Montgomery (1905) spoke of the "piece of deep ground probably of Tertiary age or even older near Colreavy's Dam". There is a curious reference, also, in Maitland (1907), to the presence of lateritic debris in a bed containing fossil Eucalypt leaves, in a bore on Government Reserve 23 near Coolgardie. This almost certainly refers to Rollo's Bore, and Maitland advocated a pre-Tertiary age for the laterite on the basis of his correlation between the Eucalypt-bearing beds and the Older Gold Drifts of Victoria.

We have been unable to locate any specimens of entire leaves from the Coolgardie sediments. Sketches of some of the leaves are, however, in the library of the School of Mines, Kalgoorlie.

FIGURE 2.



SECTION THROUGH COOLGARDIE DEPRESSION (line X-Y, figure I) SHOWING CONFIGURATION OF BASEMENT

These were kindly made available to the authors by Mr. W. M. Cleverly, Lecturer in Charge of the Geology Department of the School of Mines. The drawings are not very satisfactory but one of them, almost certainly, is of a specimen of *Nothofagus* sp.

During the past fifty years most authors, when they have committed themselves, have accepted Blatchford's estimate of a late Tertiary or sub-Recent age for the Coolgardie sediments.

Samples Studied

A recent reorganization of the collections of the West Australian Museum brought to light three samples of sediments collected from Rollo's Bore and the immediately adjacent Rollo's Shaft. These were submitted for examination to the Department of Geology, University of Western Australia, by the Museum Director (Dr. W. D. L. Ride). Only two of the samples were marked with sampling depths, although these apparently came from fairly widely spaced horizons in the borehole. Subsequently, another sample from the Coolgardie depression was made available to the authors by the Government Geologist of Western Australia (Mr. H. A. Ellis). This specimen, a fragment of boghead coal, came from Olsen's Claim and has been analysed and described by Simpson (1899). Details and brief descriptions of the four samples studied are given below.

Geol. Survey of Western Australia. Specimen No. 1087

Locality: Olsen's Claim, Coolgardie

Depth: 65 feet

Dark brown, tough, low-rank, boghead coal with a waxy lustre and conchoidal fracture. The material was difficult to ignite, but burnt slowly with a petroliferous odour when held in a bunsen flame.

W.A. Museum Specimen No. 11987

Locality: Rollo's Bore, Coolgardie

Depth: 150 feet

Brown coal, supplied in fragments, varying between 1 cm-5 cm in diameter. Some fragments were lignitic, representing single coalified pieces of wood, and others earthy, consisting of finely macerated plant debris. Most lumps contained small quantities of microscopic pyrite, and traces of compaction slickensiding were sometimes present. The ash content was high in most fragments, although some appeared to be almost devoid of mineral matter.

W.A. Museum Specimen No. 11984

Locality: Rollo's Shaft, Coolgardie

Depth: Probably 390 feet

Black, low-rank, boghead coal, with narrow intercalated bands of carbonaceous, micaceous, shale. Fragmentary leaf impressions were fairly plentiful, but too poorly preserved for reliable identification, and occasional lentoid bands of protovitrite occurred in both the boghead coal and shale partings.

The sample burnt fairly readily with a strong petroliferous odour, and is no doubt the material Montgomery (1905) called the "Coolgardie oil shale". Montgomery recorded a number of proximate analyses of samples from Rollo's Bore, although he gave no depths for the specimens examined. A typical analysis, taken from Montgomery's figures, was as follows:

H_2O 18.32%, V.M. 23.65%, F.C. 10.57%, Ash 47.46%.

Montgomery was not impressed by the possibility of exploiting the deposit as a fuel.

W.A. Museum Specimen No. 11986

Locality: Rollo's Shaft, Coolgardie

Depth: unspecified

Dark brown, low-rank, boghead coal. The sample closely resembles specimen 11984 in its physical properties, except that it contains less visible mineral matter.

Palynological Results

The humic material in all samples was readily soluble in hot 10% sodium hydroxide without prior oxidation, and plant microfossils were plentiful in the washed residues. Treatment with hydrofluoric acid was necessary to remove finely dispersed silicates.

Representative slides from the four samples discussed here are retained in the collections of the Department of Geology, University of Western Australia (Slides Nos. 41618 to 41621 incl.).

Undescribed species were present in both microfloras, but the majority of the forms observed are well known from Tertiary sediments in southern Australia, New Zealand and Antarctica. Descriptions of these species may be found in the papers of Cookson and her co-workers, and in the monograph by Couper (1953). The taxonomy of the undescribed forms will be treated by one of the present authors (D.M.C.) in a future publication.

Microfloral Lists

Specimen No. 1087. Depth: 65 feet.

Angiospermae:
- *Nothofagus* sp.—Abundant
- *Casuarinidites cainozoicus* Cookson and Pike—Common
- *Triorites harrisii* Couper—Rare
- *Cupanieidites orthoteichus* Cookson and Pike—Rare

Algae:
- *Croococcus* sp.—Abundant

Specimen No. 11987. Depth: 150 feet.

Angiospermae:
- *Nothofagus* at least two species.—Abundant
- *Triorites harrisii* Couper—Common
- *Beaupreaidites verrucosus* Cookson—Rare
- *Casuarinidites cainozoicus* Cookson and Pike—Very rare
- *Myrtaceidites parvus* forma *anesus* Cookson and Pike—Rare
- *Proteacidites* sp.—Very rare
- *Tricolpites* sp.—Very rare

Gymnospermae:
- *Dacrydium florinii* Cookson and Pike—Rare
- *D. mawsonii* Cookson—Rare
- *Microcachryidites antarcticus* Cookson—Rare
- *Podocarpidites* sp.—Rare

Cycadales:
- *Monocolpopollenites* sp.—Rare

Filicales:
- *Gleichenia circinidites* Cookson—Common
- *Cyathidites* cf. *C. minor* Couper—Rare

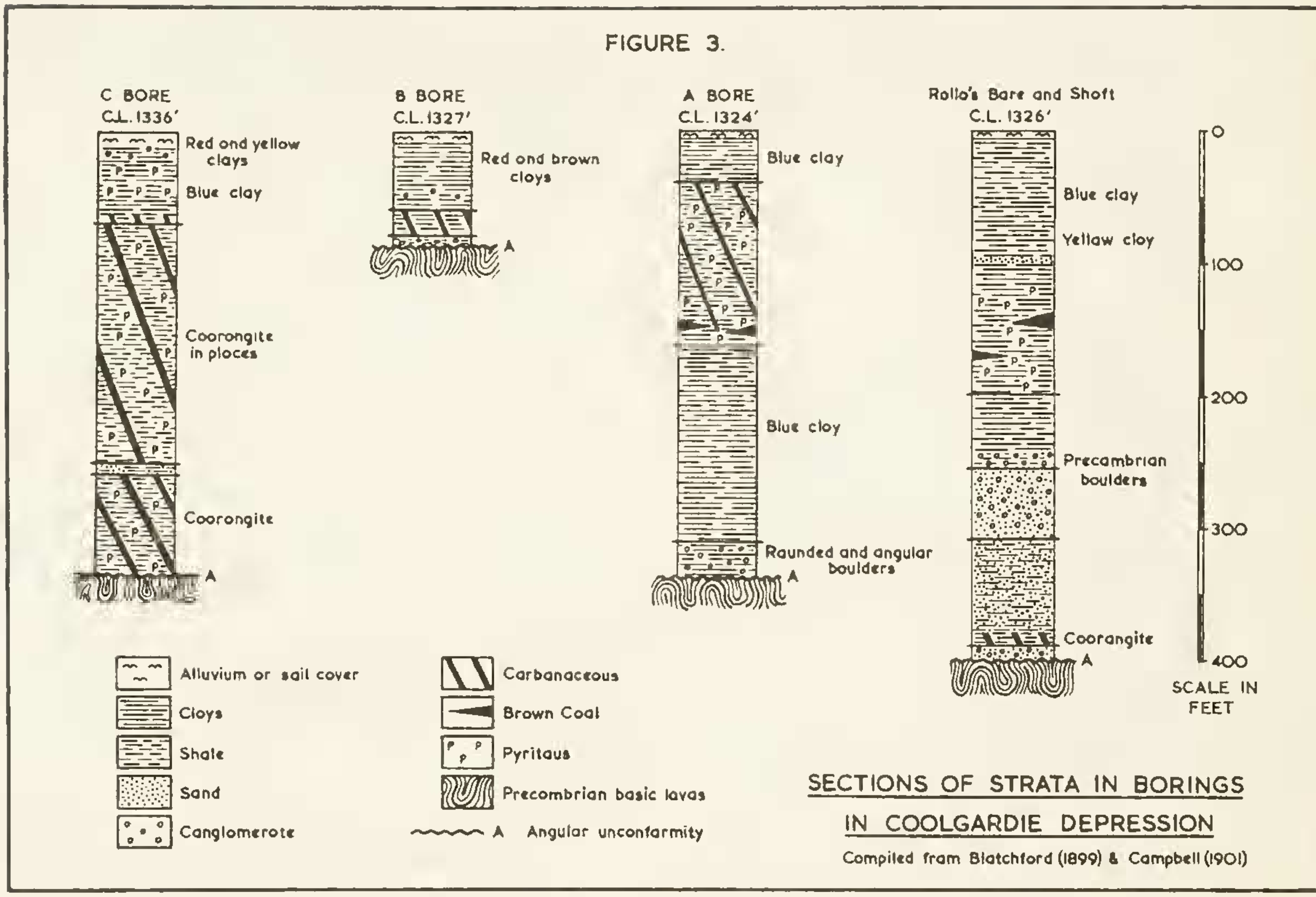


FIGURE 3.

SECTIONS OF STRATA IN BORINGS IN COOLGARDIE DEPRESSION

Compiled from Blatchford (1899) & Campbell (1901)

Specimen No. 11984. Depth: Probably 390 feet.

Angiospermae:
- *Nothofagus* at least two species.—Common
- *Triorites harrisii* Couper—Rare
- *Beaupreaidites verrucosus* Cookson—Rare
- *Tricolpites* sp.—Rare

Gymnospermae:
- *Dacrydium florinii* Cookson and Pike—Rare
- *D. mawsonii* Cookson—Rare
- *Microcachryidites antarcticus* Cookson—Rare
- *Podocarpidites* sp.—Rare

Filicales:
- *Gleichenia circinidites* Cookson—Very rare

Algae:
- *Botryococcus braunii* Kutz.—Common

Specimen No. 11986. Depth: unspecified.

Angiospermae:
- *Nothofagus* at least three species—Common
- *Triorites harrisii* Couper—Common
- *Myrtaceidites parvus* forma *anesus* Cookson and Pike—Rare
- *Banksia* sp.—Rare
- *Proteacidites annularis* Cookson—Rare
- *Cupanieidites orthoteichus* Cookson and Pike—Rare

Gymnospermae:
- *Dacrydium florinii* Cookson and Pike—Rare
- *Microcachryidites antarcticus* Cookson—Rare
- *Podocarpidites* sp.—Rare

Filicales:
- *Gleichenia circinidites* Cookson—Rare

Lycopodiales:
- *Lycopodium* sp.—Rare

Algae:
- *Botryococcus braunii* Kutz.—Abundant

Significance of Microfloras

Certain quantitative differences are apparent in the compositions of the microfloras listed. Coniferalean pollens, for example, are most plentiful in the assemblage from 390 feet, which contains also a great deal of fragmentary algal debris. The abundance of *Nothofagus* spp., however, is a feature of each microflora, and this fact, taken in conjunction with their close qualitative similarity, strongly suggests that the four assemblages were derived from essentially similar floras. Minor climatological and geographical factors can undoubtedly be invoked to explain the quantitative differences mentioned above, and it seems certain that no great time interval is represented by the sediments in the Coolgardie depression. It may be concluded, therefore, that the four samples under discussion are of much the same geological age.

The species listed all have long vertical ranges in the Australian Tertiary, and individually do not allow a precise dating of the deposit. A more refined correlation may be attempted if the Coolgardie assemblages are treated as a single palaeobotanical unit.

Comparable microfloras are found in lignites which occur in the Plantagenet Beds at isolated places along the south coast and in the Pidinga Bore on the eastern margin of the Eucla Basin. The microfloras from lignites at Denmark and Nornalup were described by Cookson (1954), and correlated by her with Microflora C from the Lower Tertiary of Victoria. This correlation was based on the presence of *Proteacidites pachypolus* in lignitic clays from a depth of 50 feet in a bore near Denmark. The same species has also been described from the Pidinga lignites (Cookson and Pike, 1954).

Proteacidites pachypolus has not, however, been found in lignites from the Plantagenet Beds

TABLE I

The distribution of some plant microfossils in Lower Tertiary deposits in South-Western Australia

Species	Localities: Denmark	Nornalup Lignite	Esperance Lignite	Coolgardie Beds
Dinoflagellata:				
Wetzeliella lineidentata Deflandre & Cookson	+	—	—	—
Palaeohystrichophora cf. *spinosissima* Deflandre	+	—	—	—
Hystrichosphaeridaceae:				
Hystrichosphaera cf. borussica Eisenack	+	—	—	—
Hystrichosphaeridium floripes Deflandre & Cookson	+	—	—	—
H. inodes subsp. *gracilis* Eisenack	+	—	—	—
Pterospermopsidaceae:				
Pterospermopsis microptera Deflandre & Cookson	+	—	—	—
Pterocystidiopsis velata Deflandre & Cookson	+	—	—	—
Xanthophyceae:				
Botryococcus braunii Kutz.	—	—	—	+
Myxophyceae:				
Chroococcus sp.	—	—	—	+
Filicales:				
Cyathidites cf. *C. minor* Couper	—	—	—	+
Gleichenia circinidites Cookson	—	—	—	+
Lycopodiales:				
Lycopodium sp.	—	+	—	+
Cycadales:				
Monocolpopollenites sp.	—	+	—	+
Coniferales:				
Dacrycarpites australiensis Cookson & Pike	+	—	—	—
Dacrydium florinii Cookson & Pike	+	+	+	+
D. mawsonii (Cookson) Cookson	+	+	+	+
Microcachryidites antarcticus Cookson	—	+	+	+
Podosporites micropteris (Cookson & Pike) Balme	—	+	+	?
Podocarpidites ellipticus Cookson	+	+	+	+
Angiospermeae:				
Nothofagus spp.	+	+	+	+
Triorites harrisii Couper	+	+	+	+
Beaupreaidites verrucosus Cookson	—	+	—	+
Tricolpites sp.	—	+	—	+
Casuarinidites cainozoicus Cookson & Pike	+	+	+	+
Cupanieidites orthoteichus Cookson & Pike	+	+	—	+
Santalumidites cainozoicus Cookson & Pike	+	—	—	—
Myrtaceidites parvus forma *anesus* Cookson & Pike	+	+	+	+
M. eucalyptoides Cookson & Pike	—	—	—	+
Banksieaeidites sp.	+	+	+	+
Proteacidites annularis Cookson	+	+	+	+
P. crassus Cookson	+	+	—	—
P. grandis Cookson	+	—	—	—
P. pachypolus Cookson & Pike	+	—	—	—
P. adenanthoides Cookson	—	+	+	+

at Nornalup, Esperance and Fitzgerald River. These occurrences are all higher in the sequence than the Denmark clays, and are, therefore, of younger age. The absence of *P. pachypolus* from the Coolgardie assemblages, together with their gross similarity to those from the younger south-coast lignites (see Table 1) suggest that the Coolgardie sequence may be correlated with part of the Plantagenet Beds. It is considered, therefore, that the Coolgardie beds are of Upper Eocene or Lower Oligocene age.

Origin of the Coolgardie Sediments

The Basement Depression

The strata in Rollo's Bore represent the thickest single section of Tertiary sediments known in that area of Western Australia lying between the Darling Fault Zone and the western margin of the Eucla Basin. In view of the small surface area of the Coolgardie deposits, such a sedimentary thickness is remarkable, and some authors have been reluctant to accept the depression as an erosional feature. Montgomery (1916, p. 93) suggested that it was of tectonic origin, and his view was accepted by Jutson (1934, p. 287), who named the sedimentary area the *Coolgardie Sunkland*. No positive evidence in favour of a tectonic origin can be put forward however, and such an explanation appears to create more difficulties than it solves.

There is no need to invoke tectonic deformation in order to explain the sedimentary thickness. Local base levels in the "deep leads" at Kanowna, which are accepted by all authorities as buried watercourses, are almost identical with those in the Coolgardie depression. Recent refraction seismograph surveys (Urquhart, 1956) have been interpreted to indicate even lower base levels in V-shaped basement valleys in the Kalgoorlie area. Examples of similar "deep leads" are to be found throughout the goldfields areas, and Clarke (1934, unpub. data) regarded them as the infilled remnants of an earlier drainage system.

Too little sub-surface information is available to enable the basement contours of the Coolgardie basin to be constructed with any confidence. However, the existing data suggest the presence of a deep, steep-sided channel skirting the western and northern margins of the depression. The basin floor slopes more gently from the south-western margin, and the basement elevation apparent in Bore B (Fig. 3) may represent a spur projecting from the southern edge of the basin. Such a basement configuration could be interpreted as the remnant of an incised meander.

A difficulty certainly arises if the basin is regarded as a product of fluvial erosion, in that no obvious continuation of the valley is apparent in the adjacent crystalline rocks. Maitland (1897) reported considerable thicknesses of valley-fill deposits in the neighbourhood of Coolgardie, but as far as can be judged from his report, the nearest of these is three or four miles to the south-east of Rollo's Bore. A continuation of the depression may exist as a narrow channel under the cover of surface alluvium and laterite, and, if so, could probably be detected only by geophysical means.

An alternative explanation is that the basin is of glacial origin, and, if so, it may date back to Sakmarian times. Such a postulate probably necessitates the acceptance of redistribution of pre-existing sediments by the advancing sea, in Middle or Upper Eocene times. Deposition of the existing sediments would then have begun in a coastal lake following the retreat of the sea from the Coolgardie area. It is interesting to note that Campbell (1906) suggested many years ago that the Lake Cowan depression was of glacial origin. This view was rejected by Jutson (1934), who believed that basement irregularities which contain the "deep leads" were formed during a period of uplift which post-dated the Tertiary marine transgression.

One of the important things to emerge from this investigation is the confirmation of the views of Montgomery (1916) and Clarke (1934, unpub. rep.) that at least some of the "deep leads" were formed in depressions which were already in existence at the time of the Eocene transgression. This is now known to be true of the Coolgardie depression and the Princess Royal Lead at Norseman. It would be surprising if it did not hold for many other similar deposits in the eastern goldfields.

Environment of Deposition of the Sediments

From their high organic content and the frequent occurrence of pyrite, it cannot be doubted that the majority of the sediments in the Coolgardie depression were formed under anaerobic, reducing conditions. Obviously, also, the surface waters were at times highly productive to enable the accumulation of the enormous numbers of microscopic algae which provide the source of hydrocarbons in the boghead coal or "oil shale". Stratification of the body of water may, therefore, be inferred, and this was apparently thermally controlled. Such conditions characterise the lacustrine environment, and the sections of strata given by Blatchford and Campbell provide a good example of the infilling of a basin by lacustrine sediments. The section in Rollo's Bore begins with sands and occasional boulders, and passes into oil shale and clays with lignites in the upper part of the succession.

Little can be deduced from the composition of the microfloras, as to the salinity of the water during the deposition of the sediments. Variations in salinity appear to favour the growth of a multiplicity of blue-green algae, and the best known deposits of present day coorongite are forming in salt lakes along the southern coasts of South and Western Australia. Nevertheless it is unwise to press such an analogy, for many genera of the Chlorophyceae show a wide tolerance to salinity.

On general palaeogeographic grounds it seems certain that the Eocene sea must have reached at least as far north as Coolgardie during its maximum transgressive phase. Marine sediments which are now correlated with the Plantagenet Beds (Singleton, 1954; McWhae, Playford, Lindner, Glenister and Balme, 1958), occur about 80 miles south-east of Coolgardie, in the vicinity of Lake Cowan and Norseman. These sediments contain beds of spongolite which almost certainly were formed in water of considerable depth (Hinde, 1910). Clarke, Teichert and McWhae (1948) suggest that in the south-eastern part of Western Australia relative sea-level was 1,500 feet higher during the Tertiary transgression than it is at present. This is very nearly the level of present topographic highs in the Coolgardie district.

No carbonates have been recorded from any of the Coolgardie bores, although Campbell reported gypsum crystals from Bore C. These probably represent secondary sulphates resulting from the interaction of $CaCO_3$ and H_2SO_4. Free sulphuric acid, a product of the decomposition of pyrite, is present in bore waters from the neighbourhood of Rollo's Bore (Blatchford, 1899, p. 46). Water from Rollo's Bore itself is highly saline and suitable for drinking only after condensation.

Indirect evidence suggests, therefore, that the Rollo's Bore sediments were deposited in a small saline coastal lake, although a fresh water origin could not be convincingly refuted. In either case there seems no doubt that deposition was initiated by epeirogenic down-warping during the Lower Tertiary. Aggradation would then have taken place either along the coast following a period of drowning and dune formation, or in a freshwater lake formed by the ponding of a river as a result of down-warping in its middle course.

The presence of well-preserved microfloras in sediments of the deep lead type at Coolgardie suggests that palynological studies may prove a useful technique in attacking physiographic problems in Western Australia. It seems, for example, that many of the present topographic patterns may be controlled by an erosional cycle of much greater antiquity than many authors have supposed. There is a wide field for investigation, and as a preliminary, an examination of the carbonaceous sediments at Mt. Kokeby (Feldtmann, 1919) would be of considerable interest.

Acknowledgments

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